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ORIGIN AND CLASSIFICATION OF THE GREENSANDS OF NEW JERSEY.[1]

CONTENTS.

INTRODUCTION.
General Stratigraphical Features.
Description of the Formations.
    Matawan Formation.
    Navesink Formation.
    Redbank Formation.
    Rancocas Formation.
    Manasquan Formation.
    Shark River Formation.
Origin of Greensand.
Genesis of the Deposits.
Source of the Materials.
Taxonomy.
General Conclusions.

INTRODUCTION.

DURING the past two years the writer has been carrying on investigations upon the Cretaceous and Tertiary formations of New Jersey under the joint auspices of the State and National Geological Surveys. A preliminary study of the whole area was followed by the mapping, with the aid of others,[2] of three United States Geological Survey atlas sheets in the northern portion of the district, and more recently by the critical examination of five type sections across the state. The results of the earlier investigations have just been published,[3] while the later work will appear in the next annual report of the State Geologist.

In an area which had received such full investigation by as competent a geologist as the late Professor Geo. H. Cook, for so many years the head of the State Survey, it was deemed advisable to act with great deliberation before proposing any important changes in the classification. Accordingly the first report to the State Geologist was limited to the fewest possible alterations in the accepted names of the formations, and the work made to conform so far as it was possible with the earlier results of the State Survey. As the work has progressed the necessity of modifying the classification hitherto adopted has become apparent, and such changes are presented at this time. The use of lithologic terms for the formations in the earlier nomenclature will be in the future discarded for place names, the older terms being retained to designate their economic equivalents. Local terms have been adopted, care being taken to select such as would characteristically represent the formations. The names of rivers, hills, and towns, in the vicinity of which typical sections are found, have been generally employed. In this manner the results of the work in New Jersey are brought into conformity with methods generally adopted at the present time in other areas.

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[1] Read before the Geological Society of America, at Boston, December, 1893.

[2] The writer had associated with him as assistants Messrs. C. W. Coman, H. S. Gane and R. M. Bagg.

[3] Rept. of the State Geologist of N. J. for 1892, pp. 167–246.

The work carried on during the past field season in portions of the area never before studied to any extent on account of the thick covering of recent deposits, reveals the fact that the divisions established chiefly from an examination in the extreme north, are remarkably persistent. This knowledge has been gained to a large extent from recent well openings and borings made at frequent intervals by the writer and his assistants. The unconsolidated character of the sediments render it possible to pursue this method of investigation throughout the region with the hope of far reaching results.

GENERAL STRATIGRAPHICAL FEATURES.

The geological formations of the coastal area of New Jersey represent a nearly complete sequence from the Cretaceous to the Pleistocene. They form a series of thin sheets which are inclined slightly to the southeastward, so that successively later formations are encountered in passing from the northwestern portion of the district toward the coast. Oscillation in the position of the shore line, and later denudation have occasioned, in many instances, a marked divergence from these normal conditions, so that detached areas are frequently found far removed from the body of the main outcrop.

The formations of the New Jersey coastal area and their economic equivalents are given in the following table :

Age.	Formation.	Economic Equivalent.	
Pleistocene	Columbia Formation		
Neocene	Lafayette "		
	Chesapeake "		
Eocene	Shark River "	Upper Marl Bed	Green-sand Series.
Cretaceous	Manasquan "		
	Rancocas "	Middle Marl Bed	
	Redbank "	Red Sand	
	Navesink "	Lower Marl Bed	
	Matawan "	Clay Marls	
	Raritan "	Plastic Clay	

The greensands characterize all the deposits from the Matawan formation to and including the Shark River formation. The glauconite appears in varying amounts and under different conditions in these several formations, so that the lithologic features are often sufficiently distinctive and persistent to be of the greatest service in the determination of the horizons. The presence of greensand has not been observed in the Raritan formation which underlies, nor in the Chesapeake formation which overlies, this series of glauconitic deposits.

DESCRIPTION OF THE FORMATIONS.

Matawan formation (Clay Marls).—On account of the extensive and typical development of the Clay Marls on the shore of the Raritan Bay in the vicinity of Matawan Creek, and along the banks of the latter stream, the name Matawan formation is proposed for the deposits of this horizon.

The greensand is a less pronounced feature than in the overlying formations. The deposits consist for the most part of dark colored clays with interbedded layers of sand, the latter becoming very pronounced in the upper portion of the formation. At some points beds of greensand appear, but they are generally thin and of very narrow geographical extent. The deposits are largely fragmental, with here and there an admixture of carbonate of lime derived from the shells of organisms.

The most extensive section is afforded by the bluffs on the shores of the Raritan Bay, between the mouth of Cheesequake Creek and the Navesink Highlands. From this point the formation extends southwestward across the state, the best exposures being found along the stream channels entering the Delaware River from the east. Both along Crosswicks and Pensauken Creeks the strata are highly fossiliferous, at the latter locality over a hundred species having been identified. In the main the forms are the same as those in the overlying Navesink formation, although some are distinctive.

From the surface outcrops the Matawan formation has been estimated to have a thickness of 275 feet.

The most striking differences both in the character of the materials and the thickness of the beds, are shown by well borings along the line of dip. A recent boring at Asbury Park penetrated the Navesink formation (Lower Marl Bed) at 400 feet, beyond which for a distance of over 400 feet typical Clay Marls were encountered. From 750 to 780 feet glauconitic layers were found, while the deposits in general are finer and more regularly stratified than in the surface outcrops to the westward.

Navesink formation. (Lower Marl Bed).—The lower Marl Bed has an extensive development throughout the region of the Navesink Highlands, in the vicinity of the village of Navesink, and along the north bank of the Navesink River, so that the name of Navesink formation may be with propriety employed.

Greensand forms the distinguishing feature of the deposits. The lower portion is frequently quite sandy, in this respect showing the change from the sandy layers of the upper portion of the Matawan formation, upon which it lies conformably, to the typical greensands of the Navesink formation. The upper portion again shows the presence of much land derived material; it is highly argillaceous and just at the top frequently arenaceous. The greensands along the thinned out western edge of the Navesink formation have been oxidized to so great an extent that their separation from the red sands of the Redbank formation is often a difficult matter.

On account of the great economic importance of the greensand beds of the Navesink formation frequent pits have been dug into it all along its line of outcrop from the northern to the southern end of the district. As a result the strata may be studied to great advantage.

A magnificent exposure is found in the great bluffs of the Navesink Highlands facing the Raritan Bay, while excellent sections are to be found along many of the streams that cut through the formation. The beds are highly fossiliferous and the most varied fauna in the New Jersey Cretaceous is found at this horizon. Between 300 and 400 species have been described.

The Navesink formation has a pretty constant thickness of 40 feet, although locally ranging from 30 to 60 feet. The deposits have been found to be remarkably persistent in character both along the strike and dip, so far as they have been examined.

Redbank formation (Red Sand).—The bright red sands of this formation afford one of the most striking features of the country throughout the marl district. They are extensively developed in the vicinity of Redbank, and on that account the name Redbank formation is proposed for the deposits of this horizon.

The strata are glauconitic throughout, although the great preponderance of coarse arenaceous sediments has facilitated the oxidation of the greensand, changing the green color of the beds to red or brown. The lower portion of the Redbank formation is often composed of black sand or sandy clay, while at the top of the formation there is an indurated clayey layer generally of a distinctly greenish color. This hardened stratum has had an important influence in the development of the topography of the marl district, and especially in the extreme north the higher hills are largely due to its presence. The fossils are in the main the same as in the preceding formations, but on account of their poor preservation have not up to the present time been very fully studied. The indurated layers have afforded the greater number.

The formation has a rather constant thickness of 100 feet.

Rancocas formation (Middle Marl Bed).—The Middle Marl Bed is not as prominent a feature in Monmouth county where the type localities for the other formations are found as farther southward. The Rancocas Creek in Burlington county cuts through the Middle Marl Bed exposing a full sequence of the deposits of that formation, while in the neighboring area extensive exposures of the strata are found.

The formation is largely a greensand, although much more highly glauconitic in the lower than in the upper half of the formation. Although the lower half is largely a pure greensand, it becomes in some portions of the state very argillaceous toward the base, forming the so-called "chocolate marl," while toward the top it becomes crowded with shells, the upper two feet characterized by the presence of *Terebratula Harlani*, the most persistent fossiliferous zone in the state. The upper half of the formation is highly calcareous, frequently appearing as limestone ledges, known as "yellow limestone," and often containing as much as 80 per cent. of carbonate of lime. It is extremely fossiliferous, and has afforded many beautifully preserved specimens of Bryozoa, Echinodermata and Foraminifera. The fossils are, in the main, different from those in the underlying formations.

The strata reach a thickness of about 45 feet.

Manasquan formation (Lower portion of the Upper Marl Bed).—The name Manasquan Marl was in an earlier publication made to include the Yellow Sand, together with the "green sand" and "ash marl" of the Upper Marl Bed of Professor Cook. For that horizon the term Manasquan formation is retained. It is typically developed in the valley of the Manasquan River and its tributaries.

Like the preceding formation it is essentially a greensand throughout, although distinctly quartzose in the lower part, and at times argillaceous in the upper layers. The fossils so far as observed are confined exclusively to the more highly greensand member, but the number of species is not large. The high percentage of soluble phosphates in the Manasquan marl has long given it a high reputation as a fertilizer.

The thickness of the strata has been estimated at 65 feet.

Shark River formation (Upper portion of the Upper Marl Bed).—The term Shark River Marl was earlier employed by the writer to embrace the "blue marl" of the Upper Marl Bed, which has been generally referred in recent years to the Eocene, although the beds are conformable with the underlying strata concerning whose Cretaceous age there is apparent unanimity of opinion.

The Shark River formation is a characteristic greensand with a slight admixture of argillaceous materials, while a hardened and stony layer is found directly at the top. The fossils are numerous, but cannot be readily compared with those from the Eocene areas to the southward. The strata of the Shark River formation have not been found at any point to exceed 12 feet in thickness.

The Shark River formation closes the series of greensand deposits. It is unconformably overlain by strata of a very different character which show evidence of marked mechanical disturbances and rapid deposition.

Throughout the entire sequence of deposits just described, the presence of greensand has been the most distinguishing feature. Its origin is therefore a matter of great importance to the understanding of the several formations, and will be briefly discussed.

ORIGIN OF GREENSAND.

Greensand has been found in greater or less amounts at nearly every geological horizon, from the Cambrian down to the present time. It is not an original deposit of clastic origin, but secondary in character. An examination into the conditions of production which surround those deposits forming upon the floor of existing seas will afford an explanation of the strata of past geological time.

Great light has been thrown upon this subject as a result of he deep-sea dredgings which have been made in recent years by the vessels sent out on scientific expeditions by the various governments of Europe and our own. The most important of these expeditions has been that of the Challenger, sent out by the British government in the years 1872–76. In the report upon the Deep Sea Deposits recently published as a result of that expedition, Professors Murray and Renard, the authors, present the latest results upon the character and distribution of greensand, and, at the same time, propose a theory to account for the chemical changes which have taken place to produce the mineral glauconite which characterizes all greensand deposits.

A typical greensand is composed of glauconite associated with greater or less amounts of land-derived material. Among the more common minerals thus found are quartz, feldspar, hornblende, magnetite, augite, zircon, epidote, tourmaline and garnet, together with fragments of the continental rocks, such as gneiss, mica-shist, granite, diabase, etc. A variable amount of calcareous matter derived from the shells of organisms is also present.

The glauconite occurs in minute grains, seldom exceeding 1 mm. in diameter, although they may become agglomerated into nodules several centimeters in diameter by means of a phosphatic cement. The grains are always more or less rounded, and at times mammillated, with irregular surface outline. They are generally black or dark green in color, but become brighter green upon being crushed. The surface of the grains is sometimes covered with fine punctures, while at other times it is smooth and shining. Some of these glauconitic grains are distinct internal casts of foraminifera, and of other calcareous shells, but more often they only reproduce indistinctly the form of the chambers, or show no definite connection with the organisms in which they originated.

It is estimated that greensand deposits cover approximately 1,000,000 square miles of the sea floor. They are found limited to those portions adjacent to the coasts, and, for the most part, along the higher parts of the continental slopes where land-derived materials are deposited in perceptible, yet small amounts. The production of glauconite seldom reaches to greater depths than 900 fathoms, and most commonly takes place between 100 and 200 fathoms. The entrance of large rivers into the sea or the prevalence of strong currents would tend to interfere with its formation, so that the area of distribution of greensand is seldom continuous for great distances.

Although greensand is not known to be formed except in the presence of land-derived materials its production is accomplished through the intervention of foraminifera. Their connection with the formation of glauconite was first shown by Ehrenberg[1] in 1855 as the result of a study of greensand from many deposits in Europe and America. Professor Bailey[2] the succeeding year stated that the formation of greensand is likewise taking place on the floor of existing seas, and under the same conditions that existed in past geological ages.

According to Murray and Renard the chambers become filled with muddy sediment, and "if we admit that the organic matter enclosed in the shell, and in the mud itself, transforms the iron in the mud into sulphide, which may be oxidized into hydrate, sulphur being at the same time liberated, this sulphur would become oxidized into sulphuric acid, which would decompose the fine clay, setting free colloid silica, alumina being removed in solution ; thus we have colloid silica and hydrated oxide of iron in a state most suitable for their combination." The potash which is necessary to complete the composition of glauconite may be derived from the decomposition of the fragments of crystalline rocks or their common constituents, orthoclase and white mica.

Two conditions then are requisite for the production of glauconite, first the deposition of mineral particles of land-derived origin; and second, the presence of foraminifera. In the absence of either the production of greensand will not take place. It is further seen that the formation of greensand is retarded and finally ceases altogether as the amount of deposition of land-derived materials increases adjacent to the coasts. Only then within circumscribed limits, which are constantly subject to modification, is the production of greensand possible.

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[1] Abhandl. d. k. Akad. d. Wissenschaften zu Berlin, 1855, pp. 85–176.

[2] Boston Soc. Nat. Hist., Proc., Vol. 5, 1856, pp. 364–368.

GENESIS OF THE DEPOSITS.

The opening of the Cretaceous period along the Atlantic border witnessed the deposition of large amounts of irregularly stratified sands and clays together with beds of gravel in the vicinity of the coasts. It was a period of great mechanical disturbance over the area of deposition, and both the physical and faunal characters of the strata point to the close proximity of land, while enclosed basins doubtless existed for a portion of the time.

With the opening of the epoch of greensand deposition, as represented in the Matawan formation, much the same conditions at first prevailed. Alternating beds of sand and clay were laid down, but gradually the coarser elements disappeared, deposition became less rapid and greensand was locally developed. The conditions for greensand production were not widely extended nor long existent, for successive periods of rapid and slow accumulation of materials continued to the close of Matawan deposition.

With the advent of the Navesink epoch land-derived materials became greatly reduced in volume and shortly ceased almost altogether, so that throughout the area of deposition there was formed at this horizon some forty feet of highly glauconitic greensand. Toward the close of this period terrigenous deposits became more pronounced, but the production of glauconite did not altogether cease.

With the opening of the next epoch, represented by the Redbank formation, dark sands in which the proportion of glauconite was very small were at first deposited. Throughout the whole series of beds glauconite is found distributed in greater or less amounts, but at no time did its production reach the prominence that it had during the previous epoch. The marked admixture of coarse elements throughout most of the deposits rendered them later subject to the ready percolation of water by which the complete oxidation of the glauconite was accomplished. Toward the close of the Redbank epoch finer sediments prevailed, and there is every evidence that land-derived materials found ingress to the area of deposition in gradually lessening amounts.

The succeeding Rancocas epoch was a time of slow accumulation of continental materials so that the production of glauconite went on unhindered. During the latter portion of the epoch, however, there must have been a great profusion of animal life, for the deposits show a marked admixture of carbonate of lime, while in many instances the shells are still in an excellent state of preservation. The formation of glauconite was not interrupted, although its relative proportion is at times much diminished by the great amount of carbonate of lime which may in some instances reach eighty per cent. of the whole.

The Manasquan epoch was characterized throughout by the constant formation of greensand beds, although land-derived materials in considerable amounts reached the area of deposition during the early portion of the period.

No very marked changes apparently affected the region toward or at the close of the Cretaceous, but the same conditions persisted on into the Eocene, as shown in the Shark River formation, during which period similar deposits with very different types of animal remains were accumulated. At the close of the Shark River epoch the conditions favorable for the formation of greensand ceased, not to be again revived during the period of formation of the coastal deposits in New Jersey.

The succeeding epochs gave proof of much shallower waters, while the ancient Cretaceous-Eocene sea floor frequently stood above sea level and along its landward portions constantly lost as the result of erosion. As the land rose higher and higher in late geological history further inroads were made until the deeper portions of the ancient sea bottom were exposed by the forces of denudation.

SOURCE OF THE MATERIALS.

The source of the materials which constitute the several formations of the coastal region of New Jersey has not been altogether satisfactorily explained, although the deposits indicate that they were largely derived from crystalline rocks.

That the red sandstones and shales of the Jura-Trias (Newark Formation) which adjoin the coastal series upon the landward side have not been the source of the materials is a striking fact, and one which has been largely commented on in the past. By some it has been supposed that an area of crystallines must have existed to the eastward to afford the materials for the deposits under consideration. A study of the drainage of the Jura-Trias belt which separates the coastal formations from the area of crystalline rocks beyond, is of interest, however, in showing the probable extension of the coastal deposits quite over the red sandstones and shales of the Jura-Trias to the border of the crystalline region and at the same time affords a sufficient explanation for the absence of sediments derived from the Jura-Trias itself. The evidence for this has been recently presented by Davis[1] in the National Geological Magazine, and the reader is referred to the article for a fuller explanation of the subject.

Accepting the explanation of Davis as highly probable we may look for the source of the land-derived materials out of which the greensand deposits are formed, in northwestern New Jersey, eastern Pennsylvania and southeastern New York, in a portion of that tract of crystalline rocks which stretches along the eastern side of the continent. A separation of the mineral constituents of the greensand deposits shows a preponderance of both the constituent and accessory minerals which characterize those rocks. It seems conclusive, therefore, that the area mentioned was the source of the materials for the greensand deposits of eastern New Jersey.

TAXONOMY.

The geological formations of New Jersey early attracted the attention of geologists, and Professor Peter Kalm[2] of Sweden, who was sent out in 1749 under the auspices of the Royal Academy of Sciences to make a study of the various branches of natural history in America, presents many interesting observations concerning the deposits under consideration. He spent much of his time in New Jersey.

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[1] Nat. Geog. Mag., Vol. II., No. 2, pp. 1-30, 1890.

[2] En Resa til Norra America 8vo. 3 vols. 1753-61, Stockholm. Translations in English by J. R. Forster 1st. Ed. 1770-71, 2nd. Ed. 1772, another Ed. in J. Pinkerton's Voyages, Vol. 13, 1812; in German by J. H. Murray, 1754-64; in French by L. W. Marchand, 1859.

In 1777, Dr. Johann David Schoepf[1] of Germany, visited America in order to study the geological features of the eastern portion of the continent. His observations and comparisons of the coastal plain formations, especially of New Jersey, mark considerable advance over those of Kalm. The importance of his investigations have not been very generally recognized by later writers, but he showed a remarkably keen insight into the geology of eastern America which was lacking on the part of some of his successors.

The first attempt at a correlation of the deposits of New Jersey with the geological column then established in Europe was made by William Maclure[2] in 1809, in his "Observations upon the Geology of the United States." In this publication the coastal deposits of New Jersey are collectively referred to the "Alluvial formation," the fourth of the main divisions of geological strata proposed by Werner. The work was subsequently revised and enlarged, appearing in book form in 1817.[3]

Professor John Finch was the first to propose a division in the coastal plain deposits of New Jersey. In his "Geological Essay on the Tertiary Formations in America" he states that what has been called the "Alluvial formation" by earlier writers "is identical and contemporaneous with the newer Secondary and Tertiary formations" of other portions of the globe.

A few years subsequent to this, Professor Lardner Vanuxem[4] through his friend Dr. S. G. Morton, presented the criteria for a more complete and definite recognition of the several members of the coastal series in which both the Cretaceous and Tertiary formations were described in some detail.

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[1] Beiträge zur mineralogischen Kenntniss des östlichen Theils von Nord Amerika und seiner Gebürge. 8vo, 1787, 194 pp. Erlangen.

[2] Amer. Phil. Soc. Trans. Vol. 6, 1809, pp. 411–428. Translation in Journal de Physique, Vol. 69, 1809, pp. 204–213 and Vol. 72, 1811, pp. 137–165.

[3] Philadelphia, 8vo, 130 pp. Also in Amer. Phil. Soc. Trans. new series, Vol. 1, 1817 pp. 1–92; and Leonard's Zeitschrift, Band 1, 1826, pp. 124–138.

[4] Amer. Jour. Sci. Vol. 7, 1824, pp. 31–43.

With the establishment of the official geological survey of New Jersey under the direction of Professor H. D. Rogers[1] the first attempt was made at a detailed differentiation of the local deposits. The formations, beginning at the bottom, were designated as follows: *Clays and Sands*, *Greensand*, *Limestone*, *Ferruginous Sand*, and *Brown Sandstone*. Although the various members were not clearly defined and widely different materials were included under the same division, yet the easterly dip of the strata was observed and the broader distinctions in the stratigraphy of the area were recognized.

Dr. T. A. Conrad,[2] in 1848, first suggested that the upper portion of the greensand series was of later age than the Cretaceous, a conclusion which he more fully elaborated at a later date.

The second geological survey of New Jersey, organized in 1854, under the direction of Wm. Kitchell, had as assistant geologist, George H. Cook, who a few years later became himself State Geologist, a position he held for over twenty-five years, until his death in 1889. He devoted from the first much attention to the greensands, and his classification of the strata has met with wide acceptance. It is elaborated in much detail in the Geology of New Jersey, published in 1868. The series of formations as recognized by Professor Cook is as follows, beginning with the oldest: *Plastic Clay*, *Clay Marls*, *Lower Marl Bed*, *Red Sand*, *Middle Marl Bed*, *Yellow Sand*, and *Upper Marl Bed*. Subsequently, Professor Cook[3] considered that an unconformity existed between the Eocene and Cretaceous members of the Upper Marl Bed.

There is no area in this country where the several formations have been studied more with reference to their own characteristics and less with reference to the supposed similarity of faunas and deposits with other and particularly European horizons.

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[1] Philadelphia Acad. Nat. Sci. Jour. Vol. 6, 1828, pp. 59–71.

[2] Philadelphia Acad. Nat. Sci. Jour. new ser. Vol. 1, 1848, p. 129. Philadelphia Acad. Nat. Sci. Proc. Vol. 17, 1865, pp. 71, 72.

[3] Report of the State Geologist for 1883, pp. 13–19.

The difficulties in the way of extended correlation are so great that for purposes of study it is often necessary to apply local names to the several formations of a particular district. There are, beyond a doubt, objections to the multiplication of names of geological horizons and already accepted terms should be employed as far as possible, but very frequently they prove to be inadequate for stratigraphical requirements. Such is the case in the New Jersey area.

Outside of the major divisions of the geological column it is impossible to employ the terms of European authors. All such attempts have, upon critical examination, failed to stand the test. The lithological and faunal characteristics show such wide variations that definite correlations of minor horizons are impossible. The geological formations of America must be studied first upon their own merits and only after a complete understanding of them has been gained can satisfactory comparisons be made with foreign areas. A detailed correlation of the New Jersey formations with European will therefore not be attempted.

Again the conditions under which the strata of the different portions of this country were deposited, are so varied that the same terms are not applicable over wide areas. The formations of the Interior are in a marked degree dissimilar from those of the Atlantic border, and even throughout the coastal plain very considerable differences are found in its various portions. Correlations of more satisfactory character can be made here than with foreign areas, but many obstacles debar the geologist from the full consummation of his task. It is possible to show in a general way the equivalency of the deposits upon the Atlantic border with those in the Gulf, the Interior, or on the Pacific coast, although in the case of individual formations such comparisons are of doubtful character.

Dr. White[1] in his admirable essay upon the Cretaceous of North America, discusses very critically the evidence for the correlation of the New Jersey greensands, but does not attempt to separate the individual members of the series beyond the reference of the upper member to the Eocene, as was also done by the writer[1] in his report upon the Eocene. It is impossible however, to satisfactorily correlate this upper member of the greensand series with the Eocene elsewhere, and it is not known how much of that horizon is included in it. It has been generally thought to represent the Lower Eocene of other regions. Concerning the other formations of the greensand series there seems to be little doubt of their reference to the Upper Cretaceous, although they probably do not include its earlier portions. Many of the same species have been found in the Cretaceous areas of the South Atlantic and Gulf States. Stanton[2] has recognized thirty-five species as identical in Alabama, eighty-six in Mississippi, and fifty-four in Texas. Some of the species which are very much restricted in the New Jersey area, appear to have a greater vertical range in the Gulf region. It is therefore very difficult to delimit equivalent horizons. It is not unlikely that a fuller knowledge of the formations may render it possible to make more detailed correlations, but at present it is impossible.

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[1] Bull. U. S. Geol. Survey, 82, 1891, 273 pp.

On these grounds, therefore, an independent classification of the New Jersey deposits is demanded. The objections to the use of lithologic terms have been already cited, as well as the grounds for employing the place names adopted.

GENERAL CONCLUSIONS.

The greensand strata of New Jersey constitute a conformable series of beds aggregating nearly 550 feet in thickness. During the Matawan epoch, when fully one-half of these deposits were being laid down, land-derived materials reached the sea in large amounts, frequently interfering with the formation of glauconite, which is much less prominent at this horizon than later. During the succeeding epochs the production of greensand was much more constant, although there were times when it became greatly reduced in amount on account of the advent of large amounts of sand and mud from the adjacent coasts.

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[1] Bull. U. S. Geol. Survey, 83, 1891, 173 pp.

[2] Bull. U. S. Geol. Survey, 82, 1891, p. 84.

From the known conditions requisite for the production of glauconite upon the bed of existing seas, and the possible position of the coast line in Cretaceous time, it seems likely that the greensands now outcropping at the surface were laid down from fifteen to thirty miles off the coast. Frequent changes of level no doubt took place, but the variations in the character of the deposits were probably quite as much due to fluctuations in the currents as to pronounced changes in the position of the coast line.

The marked thickening of the Matawan formation seaward, as shown by the well-boring at Asbury Park, is of interest as indicating the more permanent character of the deposition outside the area of mechanical disturbance such as characterized the shallower portions of the Matawan sea floor.

The alterations which have taken place in the exposed portions of the deposits are oftentimes widespread, and in the case of the indurated layers at the top of the Redbank formation have determined to a large extent the topography of the greensand district.

Many interesting problems are presented for further study, but it is hoped that this paper may contribute somewhat to a clearer understanding of greensand deposits in general, and those of the New Jersey area in particular.

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